FROM WASTE TO WEALTH: HOW BANGLADESH CAN TRANSFORM ITS BY-PRODUCTS INTO VALUABLE RESOURCES FOR A CIRCULAR BIO-ECONOMY

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ABSTRACT

Bangladesh is a vastly populated country with a population of more than 17 billion. Most of these populations live under the poverty line which is a direct outcome of the country's economy. Bangladesh is one of the leading exporters in various sectors. For the last two to three decades it went through a massive industrial revolution which generated a large amount of by-products from different sectors such as textile, agriculture, farms, and food. These by-products are mostly considered as wastes and disposed of in unsustainable manners causing environmental pollution and health risks. For example, the main food of Bangladesh is rice which comes from paddy and generates a huge amount of rice straws annually. This is the most abundant by-product in Bangladesh and is openly burned in the fields which emits greenhouse gases and particulate matter. Similarly, textile and food generates huge amounts of solid and liquid wastes, disposed of without proper treatment. This poses a threat to all living beings. As a matter of fact, these wastes or, by-products can contribute towards production, consumption, and value creation, reducing environmental pollution and creating social benefits. This is the vision of a circular bioeconomy, which is a system that utilizes waste and biological materials for a sustainable development. Bangladesh can be benefitted in various ways from a circular bioeconomy, such as increasing clean energy production, soil fertility improvement, promotion of green industry, creation of green jobs, and mitigation of various factors that contribute towards climate change. In this paper, we have explored the potential of circular bioeconomy in Bangladesh after reviewing the current status and prospects of eleven biotechnological applications (bioenergy, biofertilizer, bioplastic, biochar, biopesticide, biosurfactant, bioethanol, biogas, biohydrogen, biodegradable packaging, and biobased textile). The study discusses the challenges and opportunities for implementing a circular bioeconomy in Bangladesh and provides solutions to mitigate these challenges and use these opportunities. The overall aim of this paper is to create a sustainable economy for Bangladesh by introducing a circular bioeconomy that turns waste into wealth and promotes a green Bangladesh.

Keywords: *Bangladesh, circular bioeconomy, by-products, environmental impact, green jobs*

1. INTRODUCTION

Bangladesh mostly relies on conventional resource extraction and waste management practices which has resulted in severe environmental consequences, including air and water pollution, soil degradation, and loss of biodiversity. As a result, the country generates a significant amount of waste which includes agricultural residues, industrial byproducts, and municipal solid waste. This waste poses a great environmental hazard if not properly managed. However, this also presents the country with an opportunity to create a circular bio-economy (Figure 1), transforming waste into valuable resources, and progressing towards a sustainable economy. A circular bio-economy is an economy that harnesses environmental power and turns wastes into resources for economic development. This is a way of turning and using things that do not waste natural resources. A circular bioeconomy helps to use nature's resources to take care of our land, food, health, and industry so that we can live well without harming the nature. Biotechnological applications offer a range of innovative solutions for transforming waste into valuable resources promoting a circular bio-economy.

The utilization of biotechnologies presents a multifaceted approach to waste management, offering transformative solutions across various sectors. Bioenergy involves the conversion of waste into biofuels, including biogas and bioethanol, capable of generating electricity, heat, and transportation fuel. Simultaneously, biofertilizer production from waste addresses soil fertility and crop yield enhancement. The production of bioplastics from waste provides a sustainable alternative to conventional petroleum-based plastics, offering biodegradability. Biochar, derived through the pyrolysis of biomass under low oxygen conditions (Woolf et al., 2010), emerges as a carbon-rich material benefiting soil health and carbon sequestration. The production of biopesticides from waste introduces natural and environmentally friendly alternatives to synthetic pesticides, demonstrating efficacy in pest and disease control (Copping & Menn, 2000). Biosurfactants, derived from waste, find application in bioremediation and industrial processing. The production of bioethanol and biogas from waste contributes to renewable and sustainable fuel sources for transportation, electricity generation, cooking, and heating. Biohydrogen, generated through biological processes like fermentation or photosynthesis (Kapdan & Kargi, 2006), presents a clean and renewable energy option. Biodegradable packaging from waste mitigates plastic pollution, decomposing rapidly through microbial action (Scott, 2000). The production of biobased textiles from various waste materials, such as cotton, wool, silk, bamboo, hemp, and pineapple (Khalil et al., 2014), offers sustainable alternatives to petroleum-based textiles. By adopting these diverse biotechnological approaches, Bangladesh can effectively convert waste into valuable resources, foster new job opportunities and industries, and simultaneously alleviate its environmental footprint.

Bangladesh faces a lot of challenges in meeting its domestic demand for energy, fertilizers, pesticides, and other essential and necessary products. The country relies heavily on imports for these products, which exposes it to the risks of global market fluctuations, supply disruptions, and affecting the country's economy. Moreover, Bangladesh suffers from severe environmental pollution and degradation due to its improper waste management practices. The major portion of its municipal solid waste is disposed of in open landfills, where it emits methane and other greenhouse gases that contribute towards climate change. Furthermore, the excessive use of synthetic fertilizers and pesticides results in water contamination and soil erosion. For overcoming these challenges, Bangladesh can utilize the biotechnologies to produce these products locally from its abundant biological resources or, wastes. This would make the country able to reduce its dependence on imports, increase its energy security, and create new opportunities for sustainable economic development (Table 2) and green employment generation (Table 4). However, biotechnologies could be applied to produce biofuels and biofertilizers from waste biomass, which could provide alternative sources of energy and nutrients for agriculture and industry. Additionally, biotechnologies could be utilized to produce bioplastics, biobased textiles, and other bio-based products from plant materials, which could offer new solutions for material innovation and sustainability.

1.1 Objective of The Study

This study explores how biotechnologies can enhance the economic sustainability of Bangladesh, a developing country that relies heavily on imports with the introduction of a circular bioeconomy. It also discusses the challenges (Table 3)and opportunities for applying biotechnologies in the country (Table 1). The study aims to create economic development (Table 2) and green employment opportunities (Table 4) through biotechnological applications while addressing the social issues that arise from them.

2. METHODOLOGY

To find suitable results about how circular bio-economy can be applied in Bangladesh, the study used appropriate methods. The methods are as follows.

- **Identification of Prevailing Biotechnologies**

Works of literature have been reviewed for the identification and documentation of the currently applied biotechnologies in Bangladesh. In this process, primary and secondary sources have been used.

- **Analysis of Applicability of Biotechnologies**

For the feasibility, and adaptability of these biotechnologies, necessary strategies have been evaluated to address the potential applications of biotechnologies.

- **Assessment of Economic Impact**

The current status of biotechnologies has been stated along with the potential applications of biotechnologies, which have been explored within the specific context of Bangladesh.

- **Identification of Challenges and Mitigation Strategies**

Challenges faced when implementing biotechnologies have been identified. Mitigation strategies have been suggested to address these challenges effectively.

- **Assessment of Employment Opportunities**

Investigating the application of biotechnologies in other countries of the world, employment opportunities have been assessed.

3. RESULTS

3.1 Prevailing Methods of Biotechnologies

Biogas, bioenergy, biofertilizers, and biopesticides are the four biotechnologies that are currently used in Bangladesh, but not at a large scale. Biogas is produced from organic waste and used for cooking, lighting, and electricity generation. Bioenergy is derived from biomass, such as agricultural residues, and used for heating and power production. Biofertilizer is a natural fertilizer mainly animal wastes that contains living microorganisms that increase soil fertility and crop productivity. Biopesticide is a biological agent that controls pests and diseases without harming the environment or human health.

The renewable energy capacity in Bangladesh in 2021 was 567 megawatts (MW) (IRENA, 2022). The annual potential capacity of biogas production from agricultural residues in Bangladesh is estimated at 9693 million m3/year and was calculated to be 223 PJ/year equivalent to 7075 MW, close to the (88%) national energy demand (Rahman et al., 2018). Organic fertilizers, which are a type of bio-fertilizer, are used in Bangladesh at a rate of 60-70,000 tonnes per year, with a market value of Tk 105-120 crore and a growth rate of 30% annually (The Business Standard, 2021). The market size of biopesticides in Bangladesh is estimated to be Tk 50 crore (around $5.9 million), and it is growing by 20% every year due to the increasing demand for safe food and Bangladesh produces and uses several types of biopesticides, such as Tricost 1% WP, Monexe 0.5WP, Biomax M, Lycomax, Bactro-D, Q-Phero, K-Mite, Biotrin, and Sopodo-lure. So far, 75 biopesticides have been registered in the country (Business Post, 2021).

3.2 Application of Biotechnologies

The following table (**Error! Reference source not found.**) discusses different strategies for the application of various biotechnologies.

Table 1: Strategies for the application of biotechnologies.

Methods	Application Stratigies	
Bioenergy	• Developing a national bioenergy policy and strategy • Enhancing stakeholder's capacity and awareness • Promoting improved cookstoves and other technologies	• Supporting biomass energy supply chains • Encouraging bioenergy integration • Strengthening collaboration
Biofertilizer	• Developing and promoting biofertilizer products that suit the farmers and the market. • Establishing biofertilizer standards and policies to comply with national and international regulations and support the industry	• Improving eco-friendly and socially responsible production processes saving water, energy, chemicals, and waste • Evaluating and assessing the implementation and impact of biofertilizer products for crop production, soil health, environmental protection, and economic development
Bioplastic	• Assessing the availability and suitability of different biomass sources for bioplastic production, such as conducting feasibility studies, market surveys, and environmental impact assessments • Establishing and expanding infrastructure and facilities for bioplastic production, such as securing funding, land, equipment, and human resources, and complying with the relevant regulations and standards	• Developing and improving technologies and processes for bioplastic production, such as processing biopolymers, synthesizing sugar derivatives and lipids, fermenting sugars or lipids, and shaping bioplastic products • Promoting and supporting demand and consumption of bioplastic products in Bangladesh, such as raising awareness, educating consumers, providing incentives, creating policies, and facilitating certification and labeling
Biochar	• Choosing the right biomass feedstocks that are abundant, low-cost, and high-carbon • Adjusting the pyrolysis conditions to get the best yield and quality of biochar • Analyzing the biochar properties to determine its suitability for different uses	• Testing the biochar effects on soil and plants to assess its impact on soil improvement, crop production, and environmental protection • Developing the biochar markets and policies to create incentives and awareness for biochar production and utilization
Biopesticide	• Registering and regulating biopesticides according to the Pesticide Act, 1985, and the Department of Agricultural Extension (DAE) • Adopting and using biopesticides by farmers as part of integrated pest management (IPM) practices	• Developing and promoting biopesticide products that are innovative, effective, and suitable for farmers and consumers • Evaluating and assessing the impact of biopesticides on crop production, environmental protection, and human health
Biosurfactant/ Bioethanol	• Developing and scaling up the production of biosurfactant/bioethanol from local sources • Establishing and enforcing policies and	• Exploring their potential applications in various sectors; Creating awareness and demand for biosurfactant/bioethanol

	standards that support biosurfactant/bioethanol	
Biogas	• Developing and promoting biogas products that suit the customers and the market, such as considering the availability and quality of feedstock, the efficiency and cost of biogas plants, and the distribution and utilization of biogas • Improving biogas production processes that are eco-friendly and socially responsible, such as saving water, energy, chemicals, and waste	• Establishing biogas standards and policies that comply with national and international regulations and support the industry, such as creating incentives, opportunities, and guidelines for biogas producers, consumers, and investors • Evaluating and assessing the implementation and impact of biogas products, such as measuring energy security, environmental protection, economic development, and social welfare
Biohydrogen	• Selecting biomass sources that are abundant, low-cost, and have high hydrogen potential • Developing biohydrogen markets and policies that create incentives and opportunities for producers, consumers, and investors, and communicate biohydrogen benefits and challenges to the stakeholders	• Optimizing biohydrogen production processes that vary with the biomass type and composition, the biohydrogen yield and purity, and the environmental and economic factors • Purifying and storing biohydrogen by using suitable methods and containers. Testing and comparing biohydrogen performance and compatibility in various energy applications
Biodegradable Packaging	• Increasing the production capacity of corn or maze-based materials, mushrooms, seaweed, jute, and bananas • Promoting their use among industries, especially the garment sector	• Developing and implementing policies and regulations that favor biodegradable packaging over plastics • supporting research and innovation
Biobased Textile	• Developing and promoting bio-textile products that are innovative, effective, and suitable for the customers and the market • Improving bio-textile production processes that are eco-friendly and socially responsible, saving water, energy, chemicals, and waste	• Establishing bio-textile standards and policies that comply with national and international regulations and support the industry • Evaluating and assessing the implementation and impact of bio-textile products for economic development, environmental protection, and social welfare

3.3 Biotechnologies Developing Economy

The following table (Table 2) presents the current economic situation based on different parameters such as imports, demands, and usage. It also analyzes the economic changes and improvements in Bangladesh after applying various biotechnologies in various sectors.

Table 2: Current Status and economic changes after application of biotechnologies.

Biotechnologies: Current Status	**Status after application**
Bioenergy	
• In 2020-21 total energy supply was 2,079,517 TJ (26 % from renewable sources) (BPDB, 2021) • Imported 8,103 GWH from India (Bangladesh's Power Import From India Nears Fourfold Despite Overcapacity, n.d.), and self-sufficiency was 70% (ENERGY PROFILE Bangladesh, 2020)	• Assuming that, the renewable energy share $_{2020}$ = 26%, the renewable energy comes from biomass $_{2020}$ = 99%, so, biomass energy consumption $_{2020}$ = 538,000 TJ (26% x 99% x 2,079,517 TJ) • Assuming that, Total Final Energy Consumption (TFEC) average annual growth rate = 5.5%, so, TFEC $_{2030}$ = 3,620,000 TJ (2,079,517 TJ x 1.055^10) • Assuming that, Renewable energy share in TFEC $_{2030}$ = 40% and renewable energy coming from biomass $_{2020}$ = 99%, so, biomass energy consumption $_{2030}$ = 1,430,000 TJ (40% x 99% x 3,620,000 TJ) • If Bangladesh can satisfy this consumption from Biomass

	energy, in 2030 it would be enough to replace the electricity import entirely
Biofertilizer	
• Bangladesh's fertilizer consumption of fertilizer production was 674% in 2021, (World Bank, 2023) • Demand for different types of fertilizer for the fiscal year 2022-2023 was as follows: Urea: 34.02 lakh tonnes (3.4 million); DAP: 24.14 lakh tonnes (2.4 million); TSP: 10.24 lakh tonnes (1.04 million); MOP: 14.18 lakh tonnes (1.4 million), (DAE, 2023). Bangladesh imports over 1.2 million tons of fertilizer annually, (Dhaka Tribune, 2022) • Imported 26,741 million BDT worth of fertilizer (Bangladesh Bank, 2023)	• Annual consumption = Demand + Import - Production = 94.25 lakh tonnes (9.4 million) • Assuming that biofertilizers can replace 50% of the chemical fertilizer demand • Biofertilizer replacement = 50% of annual consumption • Biofertilizer replacement = 47.13 lakh tonnes (4.7 million) • Import reduction = Biofertilizer replacement – Import = 35.13 lakh tonnes (3.5 million) • Therefore, the potential of Bangladesh to reduce its import of fertilizers if biofertilizer is produced in full scale is 35.13 lakh tonnes (3.5 million)
Bioplastic	
• Bangladesh consumed 977,000 tons of plastic in 2020, but only 31% of it was recycled (Meeting Bangladesh's Plastic Challenge Through a Multisectoral Approach, 2021) • The Bangladesh Plastic Goods Manufacturers and Exporters Association reported that Bangladesh imported plastic raw materials from 67 countries, with a total value of 2.5 billion USD in 2020 and plastic comprised 8% of the total waste generated every year, which amounted to 800,000 tons (icddr, b, 2018) • Bangladesh is a major importer of plastic and rubber articles, mainly from India, China, and Malaysia (Bangladesh Bank, 2021) • The top three importers of plastic raw materials to Bangladesh were Vietnam with 217,547 shipments, India with 37,404 shipments, and Turkey with 22,184 shipments (BPGMEA, 2021)	• The global production capacity of bioplastics was set to increase significantly from around 2.4 million tonnes in 2021 to 7.5 million tonnes in 2026. of which Asia accounted for half. By 2026, Asia's share of bioplastics production capacities is forecast to increase to 70 percent (European Bioplastics, 2021) • Assuming that Bangladesh can produce bioplastics at the same rate as the global average, which is about 0.03 percent of the total plastics production(Plastics Europe, 2021), then Bangladesh could produce about 293 tons of bioplastics in 2020 • This would be a very small fraction of the plastic consumption in the country, and would not significantly reduce the import of plastic raw materials. However, if Bangladesh can scale up its bioplastic production capacity and reach the level of the leading bioplastic producers, such as Thailand, which has a capacity of 140,000 tons per year (European Bioplastics, 2021) • Then Bangladesh could potentially reduce its plastic import by about 14 percent, assuming that the bioplastics can substitute the same amount of conventional plastics. This would also reduce the environmental impact of plastic waste and support the local jute industry
Biochar	
• Bangladesh imported 3191501.46 metric tons of char in 2016 (Bangladesh Coal Reserves and Consumption Statistics - Worldometer, n.d.)	• Assuming that the conversion rate of biomass to biochar is 55.5% (18 kg of biomass (flower waste) produces 10 kg of biochar) (Bogale, 2017) • Biomass needed to produce enough biochar to replace the imported char = Char / Conversion rate = 5750453.1 metric tons • This means that Bangladesh would need to produce about 5750453.1 metric tons of biochar from biomass to meet its char demand as in 2016.
Biopesticide	
• In 2017, Bangladesh imported over 15,106 tonnes of raw materials, which were used to produce 37,187 tonnes of pesticide products, a 6% increase in the supply of pesticides compared to the previous year (Hazardous Pesticides in Wide Use in Bangladesh, n.d.) • The annual consumption of pesticides in Bangladesh in 2023 by using the following formula, $I_{2023}= I_{2017}* (1 + r)^3= 52,750.47$ tons	• Assuming that the market share of biopesticides increases to 30% by 2023 due to increased production, marketing, and adoption of biopesticides, then the annual import of pesticides in 2023 will be, $M_{2023} = I_{2023} * (1 - s) = 36925.33$ • tons (30% market share of biopesticides) • This scenario demonstrates that Bangladesh could reduce its pesticide imports by 24.5%, (Swisscontact, 2023)
Biosurfactant	

• In April 2019, Bangladesh recorded an import value of 1,636.910 BDT million for surface active agents (CEICdata.com, 2019) • Assuming that the domestic market size of Bangladesh grows at the same rate as the global surfactants market, 35% (r), import of surfactant in 2023, $I_{2023} = I_{2019} * (1 + r)^2 =$ 2983.27 BDT million	• This means that if Bangladesh can produce biosurfactant according to her potential, the import of 2983.27 BDT million can be reduced in 2023
Bioethanol	
• Bangladesh imported 619 shipments of ethanol, brought in by 117 importers in Bangladesh from 137 suppliers (Ethanol Imports in Bangladesh - Import Data With Price, Buyer, Supplier, HSN Code, 2023)	• Around 65.36 Mt of agricultural waste from major crops is available in Bangladesh, which has the potential to produce approximately 32 Mt of bioethanol (Miskat et al., 2020), and annually, Bangladesh generates 63.00 ml of ethanol from corn, 53 ml from pumpkin, and 73.67 ml from carrot (Yesmin et al., 2020) • If Bangladesh increases its production of bioethanol, the import can be reduced
Biogas	
• Bangladesh is expected to have a gas demand of 3.508 BCFD (billion cubic feet per day) and annual gas production in 2020-21 was 892.75Bcf= 2.446 BCFD, (HCU, 2021) • Bangladesh's LNG imports in 2020 were 4 Mt, equivalent to 206,000 MMCF/year = .565 BCFD, (S&P Global, 2021a) • Gas accounted for 60.5 percent of total power production in 2022 (Bangladesh: Power Production Share by Source 2022 | Statista, 2023)	• The gas production and imports result in a substantial deficit of gas supply, amounting to 0.497 BCFD • Bangladesh can produce 13100000 cubic meters of biogas by utilizing a total amount (100%) of organic waste in 2020. If we ensure to utilize at least 10% of it, it will produce 1848 MW of electricity which will cover 10.7% of peak electricity demand in 2020 (Prospects and Potential of Biogas Technology in Bangladesh, 2016)
Biohydrogen	
• Hydrogen fuel has a higher fuel value than traditional fuels and has no harmful effects on the environment. One kg of hydrogen can generate about 33.33 kWh of energy, while petrol and compressed natural gas (CNG) can generate only 12 kWh and 14.7 kWh, respectively (Suman, M.,2021).	• The retrievable quantity of biomass is 94.16 (million tons) (M. Rahman, 2019) • Assuming that 10% can be used for biohydrogen production (94.16x 0.1= 9.42 million tons). This amount of biohydrogen can generate about 324.08 billion kWh of energy ($9.75 \times 33.3 \times 10^6$) • This means that if biohydrogen is produced at full scale in Bangladesh in 2023, then Bangladesh can reduce its energy imports
Biodegradable Packaging	
• The annual per capita consumption of plastic in Bangladesh's urban areas saw a threefold increase, rising from 3.0 kg in 2005 to 9.0 kg in 2020. However, of the total 977,000 tons of plastic consumed in 2020, only about 31 percent was successfully recycled (Meeting Bangladesh's Plastic Challenge Through a Multisectoral Approach, 2021)	• A huge portion of this consumed plastic comes from packaging. The consumption of LDPE packaging materials, such as plastic bags, experienced a fivefold increase in 2020 compared to 2005 (Meeting Bangladesh's Plastic Challenge Through a Multisectoral Approach, 2021) • Bangladesh's production of bioplastic and use of bioplastic for packaging can fix this issue
Bio Textile	
• Cotton: Cotton imports are estimated to be 8.1 million bales (480 lb each) in 2020/21 and 8.3 million bales in 2021/22 (USDA, 2021b) • Synthetics: In 2021, Bangladesh emerged as the 16th largest global importer of Synthetic Fabrics, with imports valued at $52.3M. Synthetic Fabrics ranked as the 224th most imported product in Bangladesh that year. The primary countries from which Bangladesh imported Synthetic Fabrics were China ($36.9M), South Korea ($5.3M), Thailand ($3.46M), Hong Kong ($2.35M), and	• Bangladesh's jute production in FY22 was 1,518 thousand metric tons (Emerging Rating, 2022), which can be used to replace cotton. • Qmilch makes fabric from protein in soured milk that is normally wasted, and Bangladesh produced 10.6 billion liters of milk in 2019/20 and 11 billion liters in 2020/21 and wasted about 10% of it, which could produce 424 million m^2 and 440 million m^2 of bio-textile respectively. If bio-textiles from spoiled milk can replace synthetic fabric, It could reduce synthetic import by about 26% (The Asian Age, n.d.)

Vietnam ($1.86M). (The Observatory of Economic Complexity, n.d.)	

3.4 Circular Bio-economy: Challenges and Mitigations

The following table (Table 3) discusses different obstacles that Bangladesh faces in the application of various biotechnologies and explains the mitigation strategies.

Table 3: Challenges and Mitigations of Application of Biotechnologies

Challenges	Mitigations
Bioenergy	
• The availability and quality of biomass feedstock can vary depending on the season, weather, market price, and other factors.	• The govt. and the private sector can collaborate to establish a biomass supply chain that can collect, store, transport, and distribute biomass from various sources, like agricultural residues, forest residues, municipal solid waste, and animal waste.
Biofertilizer	
• Contamination of heavy metals and pathogens in bio-based fertilizers poses a risk to human health and the environment.	• Strict quality control and monitoring of the raw materials and the production process can reduce contamination.
Bioplastic	
• Bangladesh does not have enough land or water resources to grow sufficient crops for bioplastic production.	• Bangladesh can explore the potential of cultivating its own crops for bioplastic production, such as sugarcane, cassava, or sweet potato. These crops can grow well in tropical climates and have high starch content, which is suitable for bioplastic production.
Biochar	
• The lack of standardized methods and protocols for biochar characterization, application, and evaluation.	• For biochar characterization, application, and evaluation, existing international standards and best practices can be consulted and adapted to the local context.
Biopesticide	
• High cost and limited availability of biopesticides compared to chemical pesticides.	• Providing incentives and subsidies for biopesticide production and use, as well as creating market linkages and distribution networks.
Biosurfactant	
• The yield and productivity of biosurfactants depend on various factors, such as the type and strain of microorganisms, the composition and pH of the culture medium, the temperature and oxygen level of the fermentation process, and the downstream processing methods.	• It is possible to optimize the conditions for fermentation and use improved bioreactor systems. The conditions include the microorganisms, the medium, the temperature, the oxygen, and the downstream methods. These affect the biosurfactant production of microorganisms.
Bioethanol	
• The technical barriers and knowledge gaps in converting biomass to bioethanol, such as pretreatment, enzymatic hydrolysis, fermentation, and distillation.	• By investing in research and development, technology transfer, capacity building, and demonstration projects the situation can be overcome. Also, to adopt advanced technologies such as enzymatic hydrolysis, simultaneous saccharification and fermentation (SSF), and consolidated bioprocessing (CBP) that can improve yield and efficiency.
Biogas	
• Insufficient supply of raw materials, such as cow dung and poultry waste, due to the declining number of livestock and poultry farms in rural areas.	• Livestock and poultry farming can be promoted and supported by the government and NGOs. The farmers can be trained and encouraged to adopt improved animal husbandry practices and feed management.

Biohydrogen	
• The lack of adequate infrastructure and technology for biohydrogen production, storage, distribution, and utilization. Biohydrogen requires special equipment and facilities to ensure its safety and efficiency, which are not widely available or affordable in Bangladesh.	• Looking for cooperation and help from nations or entities with greater knowledge and proficiency in this area could be the solution to the problem.
Biobased Textile	
• The lack of availability and affordability of biobased raw materials, such as organic cotton, hemp, jute, bamboo, and other natural fibers. Bangladesh relies heavily on importing cotton, which is subject to price fluctuations and environmental impacts	• Encouraging the growth and treatment of natural fibers like jute, hemp, and bamboo, which are well suited to the local climate and soil. These fibers demand less water and land compared to cotton.
Biobased packaging	
• Low performance and durability of biobased packaging materials in terms of mechanical, thermal, and barrier properties.	• Enhancing the performance and durability of biobased packaging materials in terms of mechanical, thermal, and barrier properties by using multilayer structures, coatings, additives, and blends

3.5 Opportunities for Employment

The application of biotechnologies could be a key to boost employment in Bangladesh. Even though unemployment surged from 2.32 million in the last quarter of 2022 to 2.59 million in the first quarter of 2023 (Desk, 2023), the advent of biotechnological practices might be the answer. Many countries worldwide have already started enhancing their labour force by incorporating these biotechnological practices (Table 4). Thus, Bangladesh has a substantial chance to turn this adversity into an advantage by providing these opportunities to jobless individuals.

The following table (Table 4) shows employment in various biotechnological activities in different countries.

Table 4: Employments in various biotechnological activities.

Methods	Employments in various biotechnological activities
Bioenergy	Bioenergy systems create 1.27 man-years of employment per GWh of electricity produced, with CHP systems creating more than 2 man-years per GWh, depending on technology and scale (Thornley et al., 2008)
Biofertilizer	-
Bioplastic	In the EU, the bioplastics industry generated 15,000 new jobs this year (Exciting Careers in the Bioplastics Industry - Renewable Carbon News, 2023)
Biochar	-
Biopesticide	-
Biosurfactant	-
Bio-ethanol	USA's Ethanol industry in 2022, created 78,802 direct jobs, and indirectly 342,876 jobs (Statista, 2023)
Biogas	In 2018, Germany's biogas industry created 30,800 direct and indirect jobs along with other countries such as Italy, UK, and France (Statista, 2023a)
Biohydrogen	-
Biodegradable Packaging	-
Biobased Textile	-

3.6 Circular Bio-Economy Flow Chart

Circular bio-economy (Figure 1) uses biotechnology to produce various products from biomass while minimizing waste and environmental impact. It follows a circle with 11 segments, each representing a different biotechnological method. The methods are bioenergy, biofertilizer, bioplastic, biochar, biopesticide, biosurfactant, bioethanol, biogas, biohydrogen, biodegradable packaging, and biobased textile.

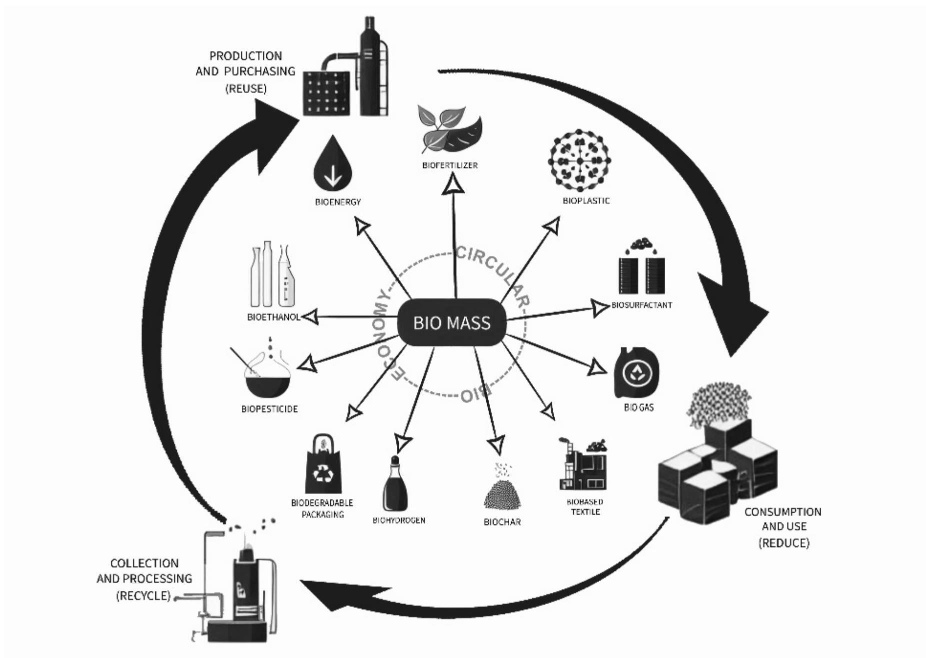

Figure 1: Circular Bio-Economy. Source: Illustrated by the authors.

The circle (Figure 1) also has three arrows pointing in a clockwise direction, indicating the application of the 3R principle (reduce, recycle, reuse) in the production, consumption, and collection stages; it illustrates how a circular bioeconomy can create a sustainable and circular system of using biological resources.

4. CONCLUSIONS

By examining various applications of biotechnology, this study has investigated the potential of implementing a circular bioeconomy in Bangladesh. The aim is to convert by-products from different sectors into valuable resources, thereby promoting sustainability and competitiveness within the country's economy while minimizing environmental and social impacts (Table 2). However, several challenges must be addressed and opportunities must be seized for Bangladesh to fully realize this potential. These include the need for policy support, public awareness, technological innovation and market development (Table 1). To tackle these issues and foster a circular bioeconomy, the study proposes several solutions (table 3). Ultimately, the implementation of the 3R strategy (Reduce, Recycle, Reuse) is emphasized as circular for achieving a green and self-sufficient Bangladesh. By embracing this strategy, the country can effectively combat pollution, poverty, unemployment, and import dependency. In addition, Bangladesh has the potential to serve as a shining example for other developing nations who are aiming to embrace a circular bioeconomy (Figure 1). As a result, it is crucial for all parties involved in Bangladesh to collaborate and collectively execute the 3R strategy, thereby transforming waste into valuable resources.

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